MiniBooNE and SciBooNE experiments, and their cross section analyses

outline

1. **Booster Neutrino Beamline (BNB)**
2. **MiniBooNE detector**
3. **SciBooNE detector**
4. **Conclusion**

Teppei Katori
Massachusetts Institute of Technology
(and Cordao de Ouro Chicago)
NuInt12, CBPF, Rio de Janeiro, Brazil, Oct. 22, 2012

1. Booster Neutrino Beamline (BNB)

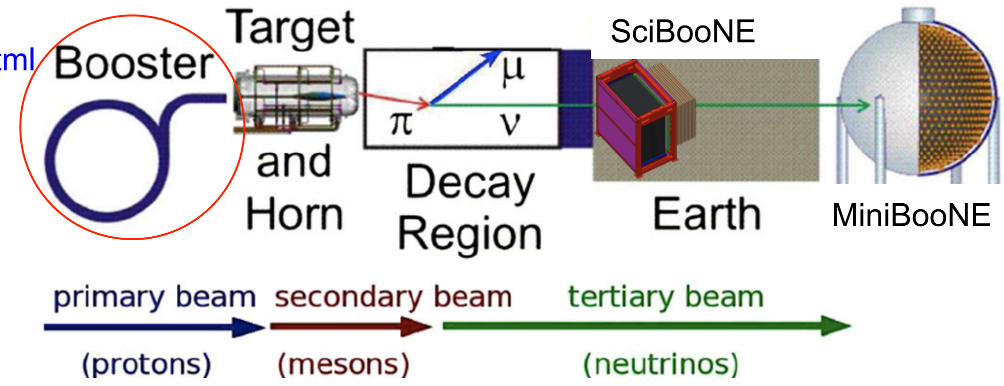
2. MiniBooNE detector

3. SciBooNE detector

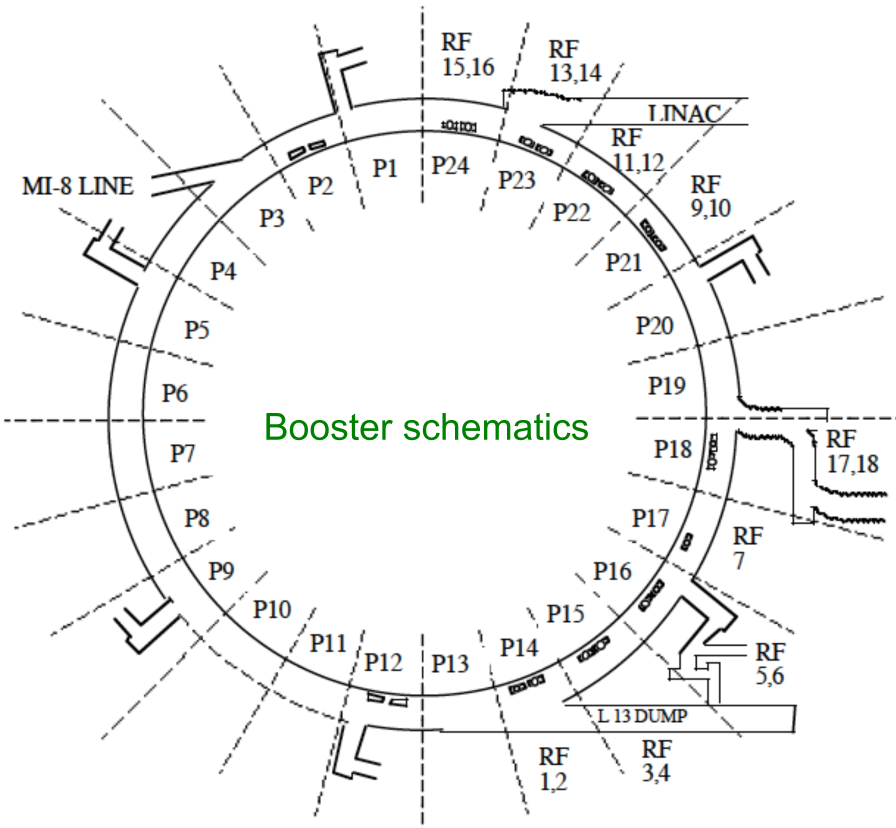
4. Conclusion

Booster Rookie book
http://www-bdnew.fnal.gov/operations/rookie_books/rbooks.html

1. Booster Neutrino Beamline



Fermilab Booster
- Constructed in 1970
- 150m diameter proton synchrotron
- 24 superperiods, 18 RFs



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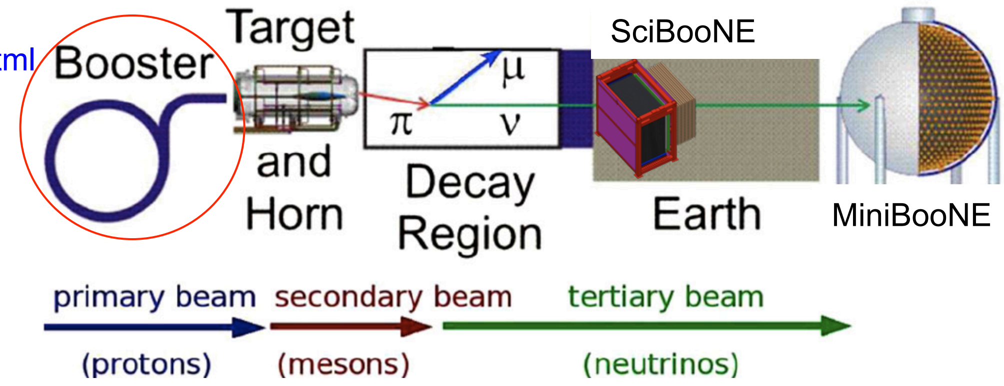

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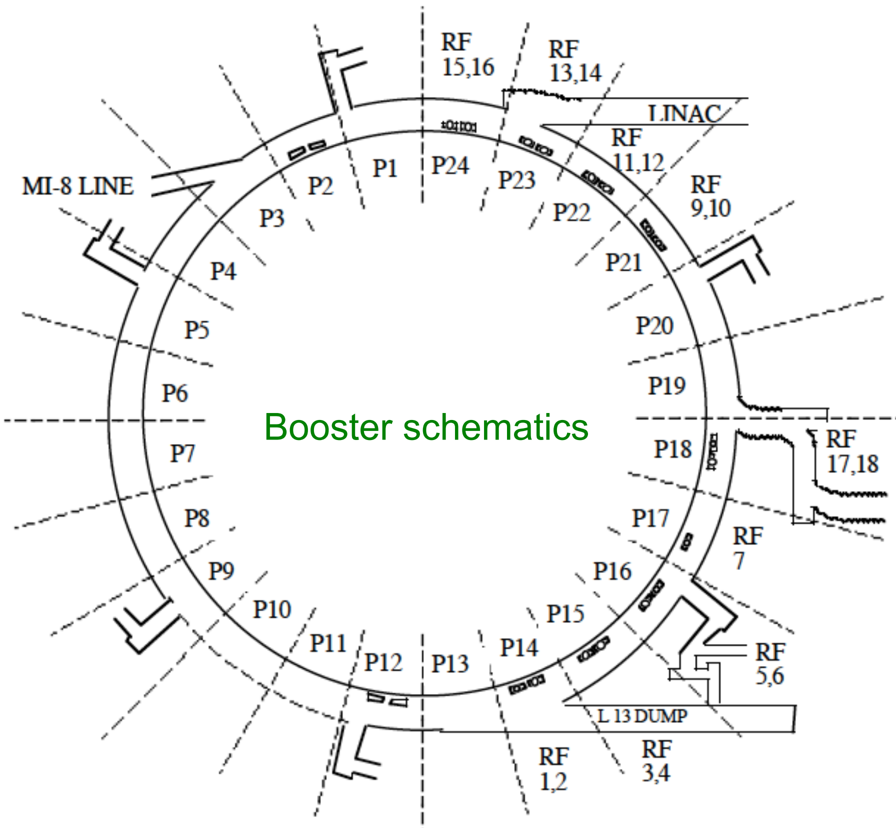
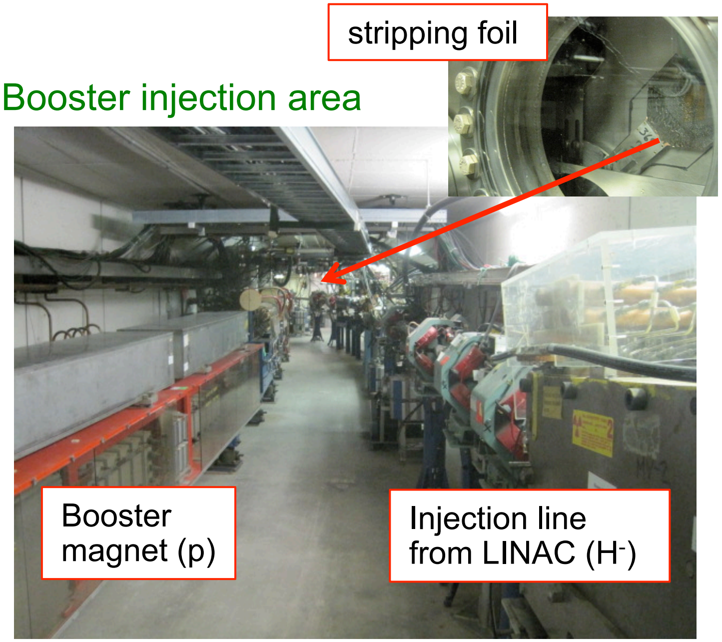
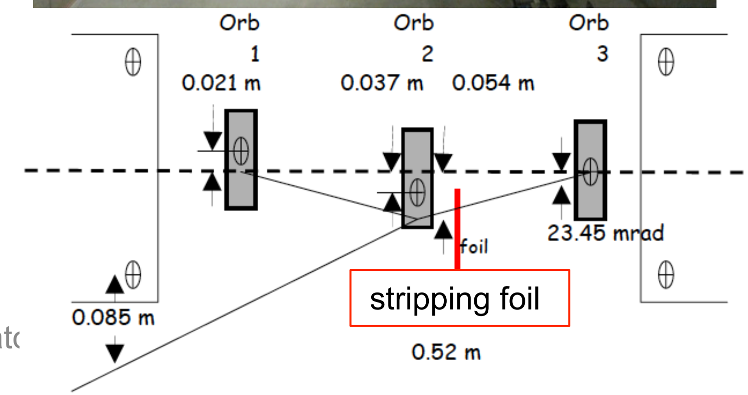


Booster injection area





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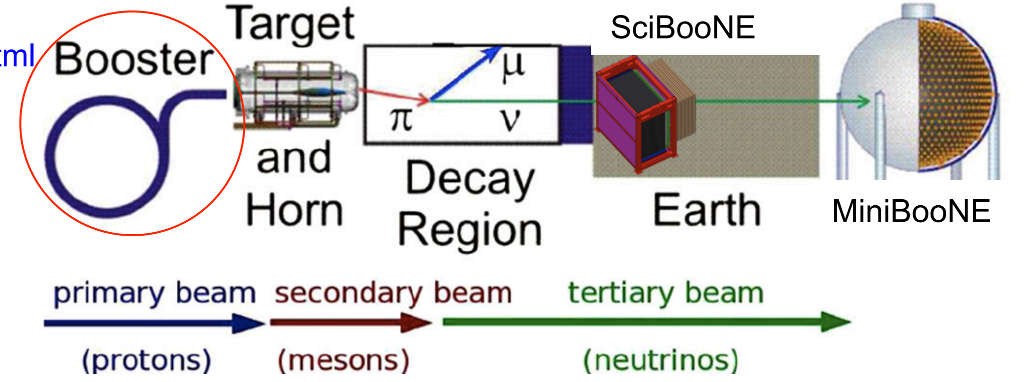

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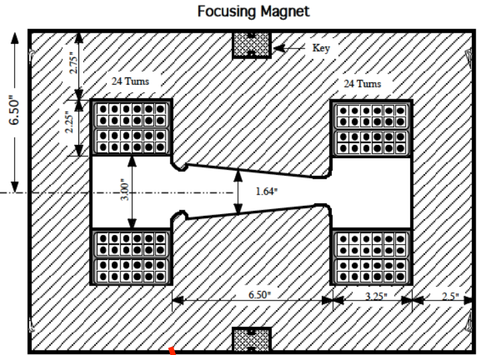
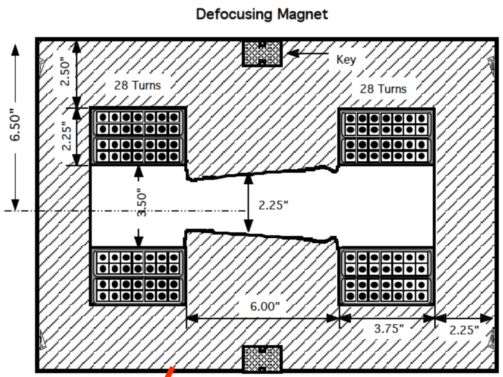
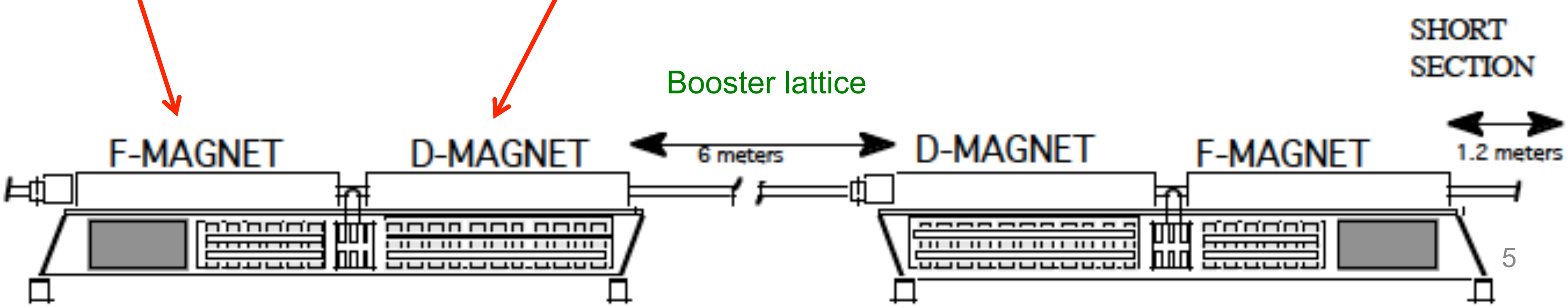
Booster magnet





Booster lattice



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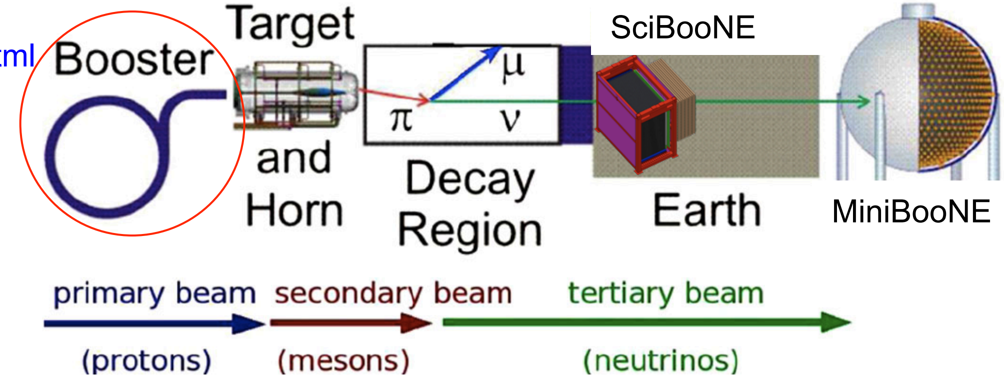

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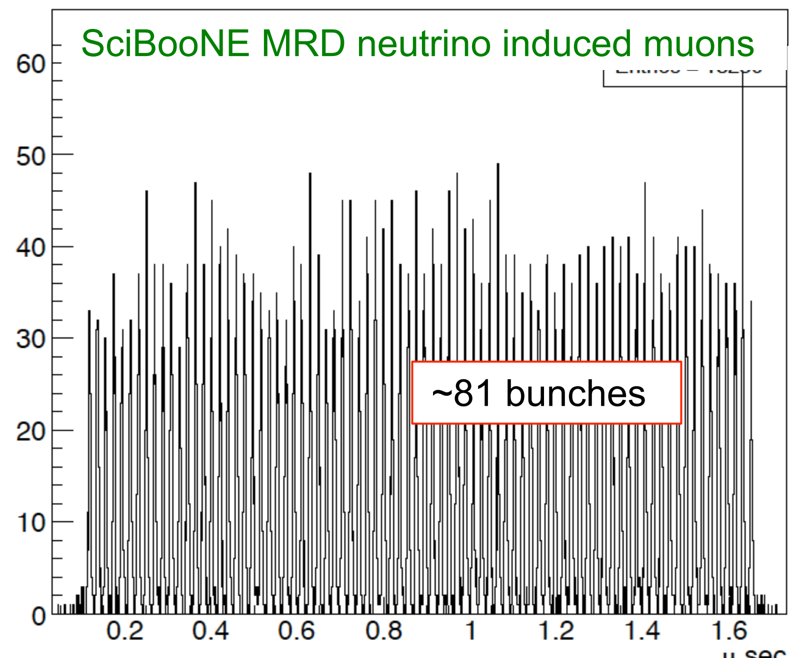
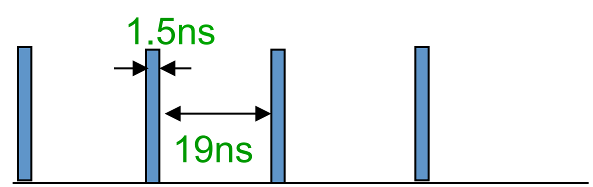
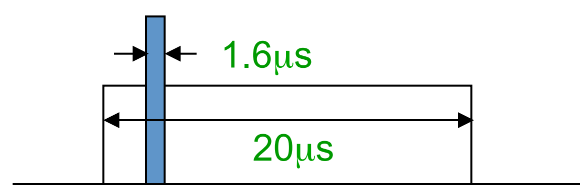
- 33ms acceleration, 20k turns, from 400MeV to 8GeV
- 84 harmonics (maximum 84 bunches)
- 3 bunches are removed, so usually 81 bunches
- 81 bunches separate with 19ns, making 1.6μs spill

Booster RF cavity





Beam micro structure



Beam macro structure

Booster Rookie book
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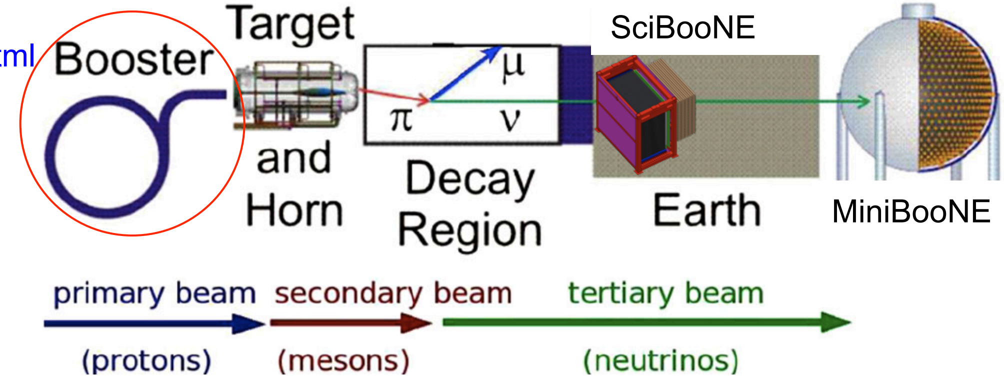

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- 3 bunches are removed, so usually 81 bunches
- 81 bunches separate with 19ns, making 1.6μs spill
- Nominal run, ~5 spills fast extraction per second (5Hz)
- 5E12 ppp (proton per pulse)
- POT is measured at 2 locations by toroids, one is official, other is cross check, and the difference of them is the 2% POT normalization error

MiniBooNE flux prediction summary paper
PRD79(2009)072002

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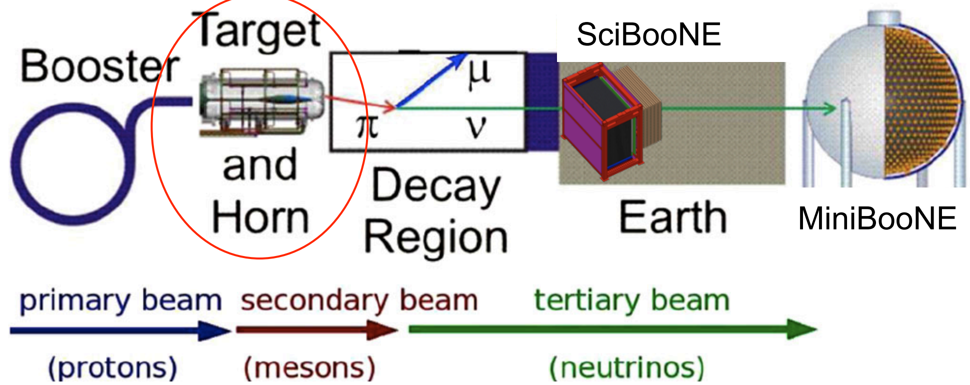
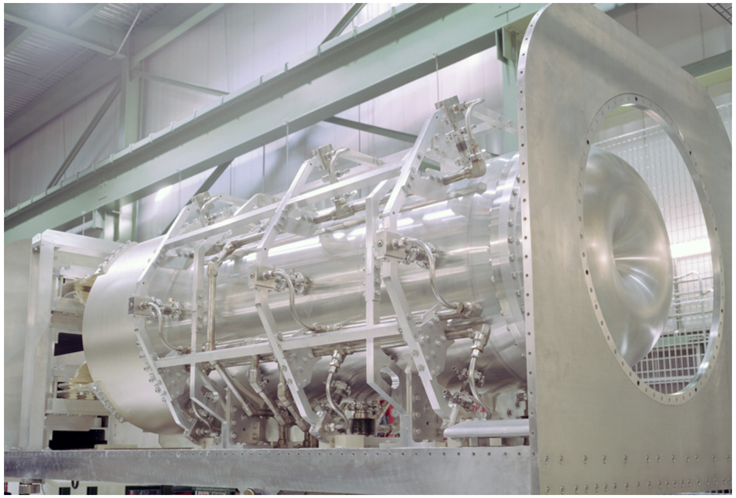


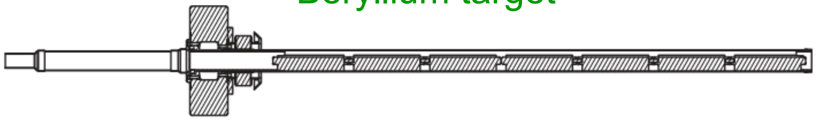
Target and magnetic horn
- Longest life time horns! (lower current?)
- Beryllium target (71 cm), 7 “slugs”
- Vibration of the horn is audible
- Magnetic focussing horn run at ~174kA (or -174kA)
- Surface current of the horn affect B-field distribution, hence secondary particle trajectory.

It affects not only normalization, but also shape of spectrum
- In total, beamline simulation (except meson production errors) makes ~4-8% normalization and shape error

Magnetic focusing horn



Beryllium target



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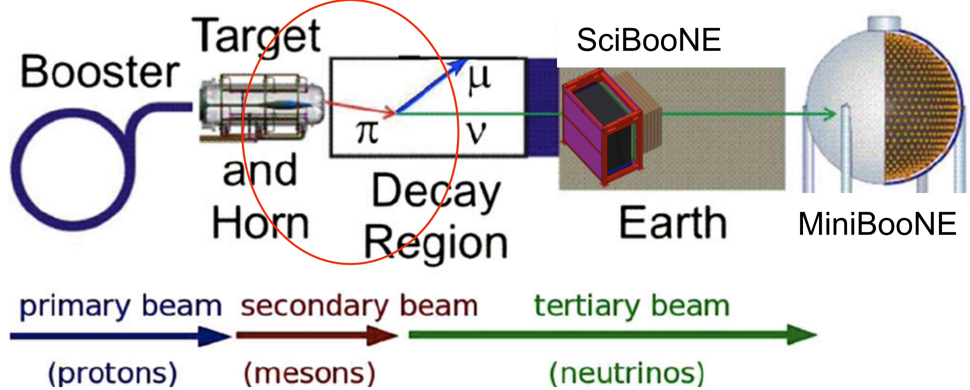
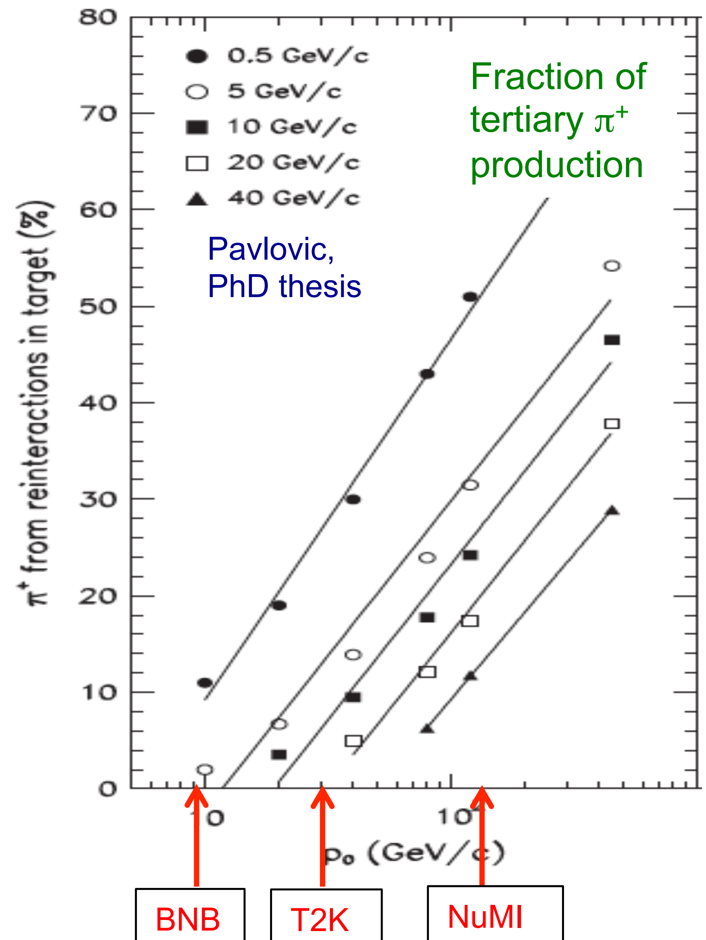


Secondary meson distribution

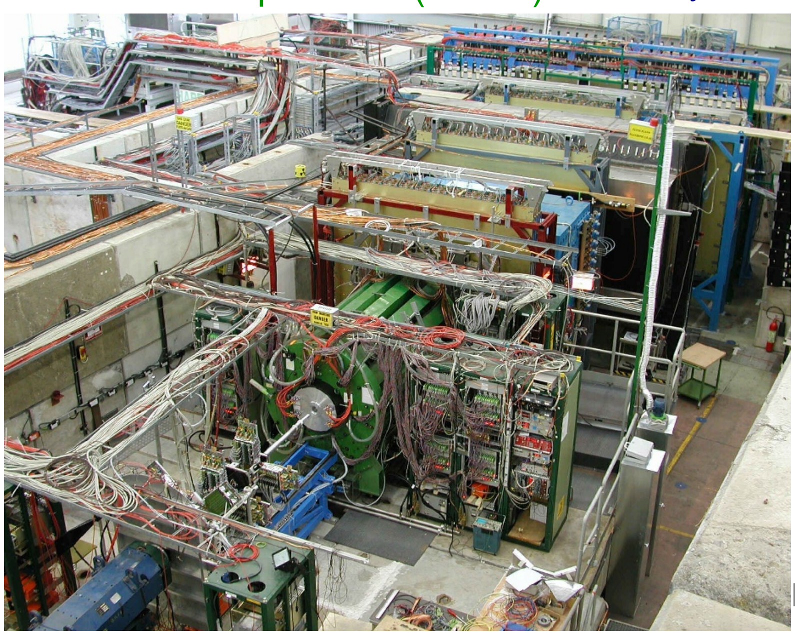
- The most important to understand ν-flux
- BNB uses GEANT4 simulation
- BNB relies on HARP data for inputs
- So far only 1 slug target data ("thin" target data) is analysed, but the secondary scattering by 7 slugs ("thick" target) is believed to be small effect, and believed to be small error

(HARP thick target data is being analysed now by Athula Wickramasinghe, U-Cincinnati)



HARP experiment (CERN)

HARP collaboration, Eur.Phys.J.C52(2007)29



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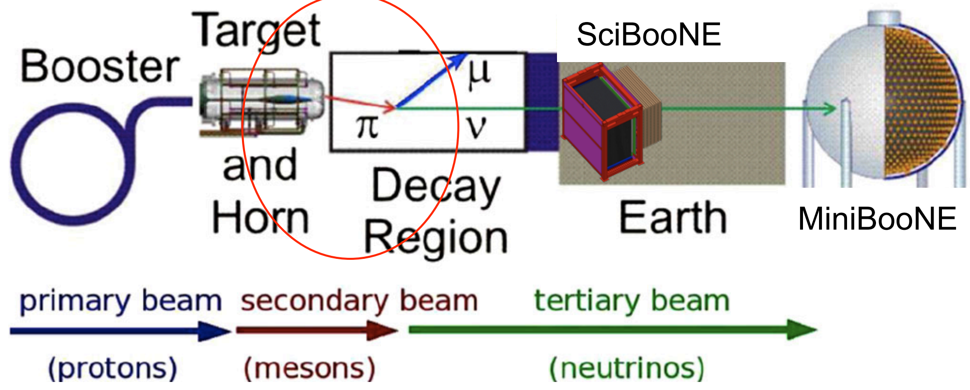

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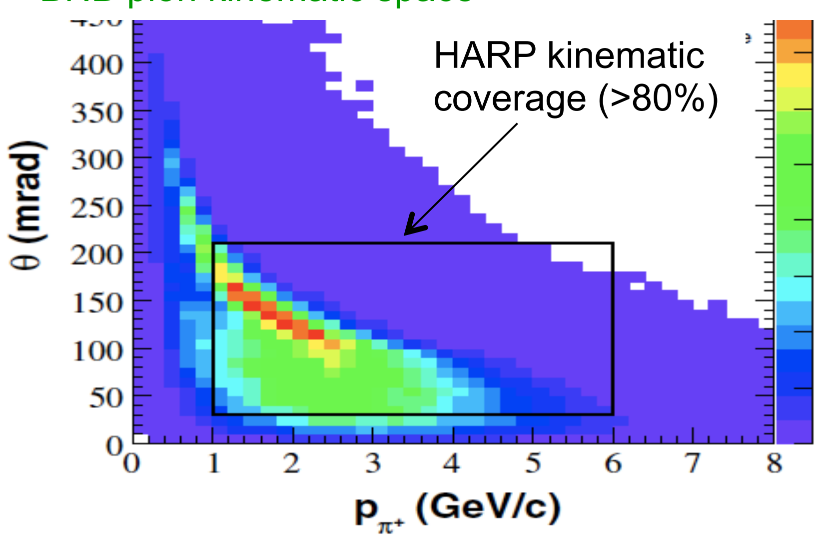
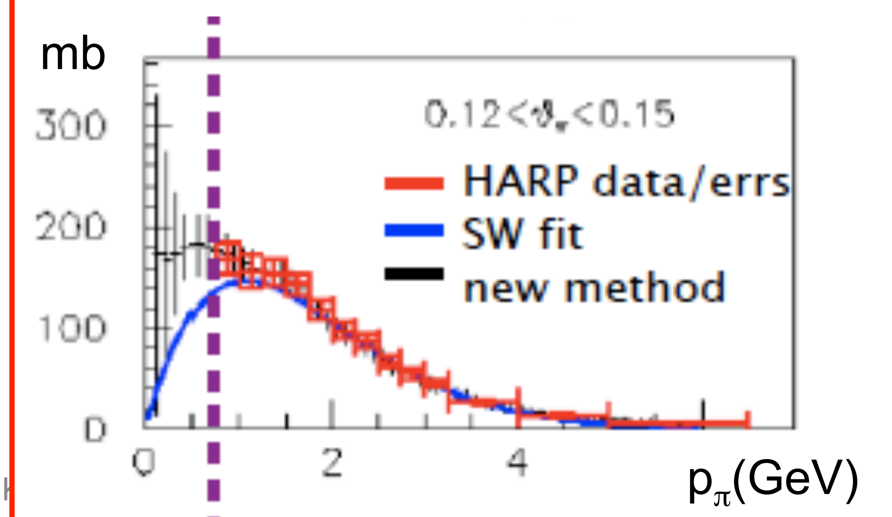
- π^+/π^--decay neutrinos are dominant, hence small K-decay error
- small HARP measurement error (5-7%) is directly applied for Eν=0.5-1.0GeV
- HARP has larger error at high E measurement, and hence high Eν prediction has larger error
- Low Eν prediction relies on extrapolation, and hence larger error
- In total, meson production give ~5-8% normalization error

BNB pion kinematic space



HARP data with 8.9 GeV/c proton beam



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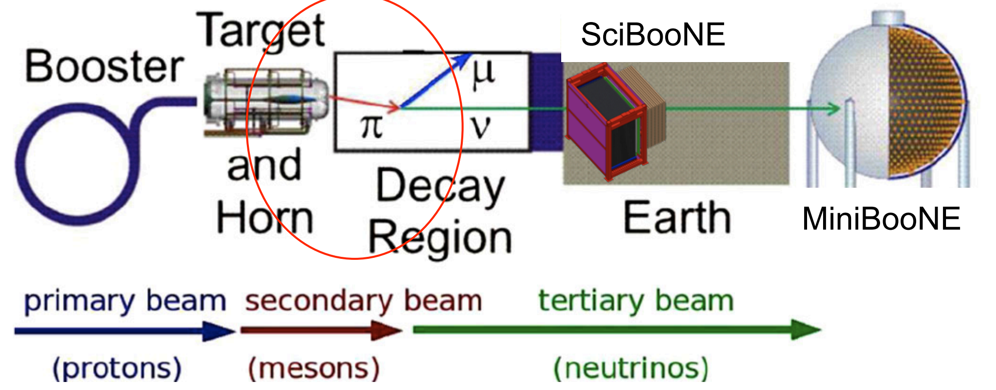

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In summary, neutrino flux prediction has ~6-12% normalization error with small shape error

More on beam systematics, see Hartz's talk on Friday

MiniBooNE collaboration
PRD84(2011)072005

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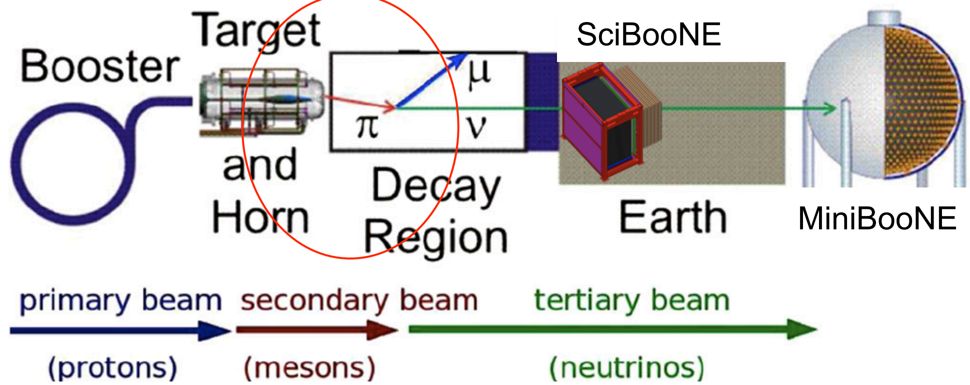

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Anti-neutrino cross section measurement

- For anti-neutrino mode analysis, errors from neutrino contamination in anti-neutrino beam contribute additional ~5% normalization error through background subtraction

Anti-neutrino xs systematics, see Grange's talk on Thursday

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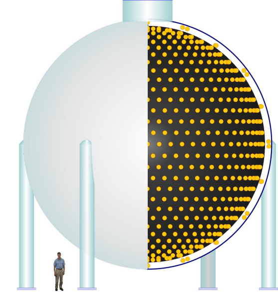
4. Conclusion

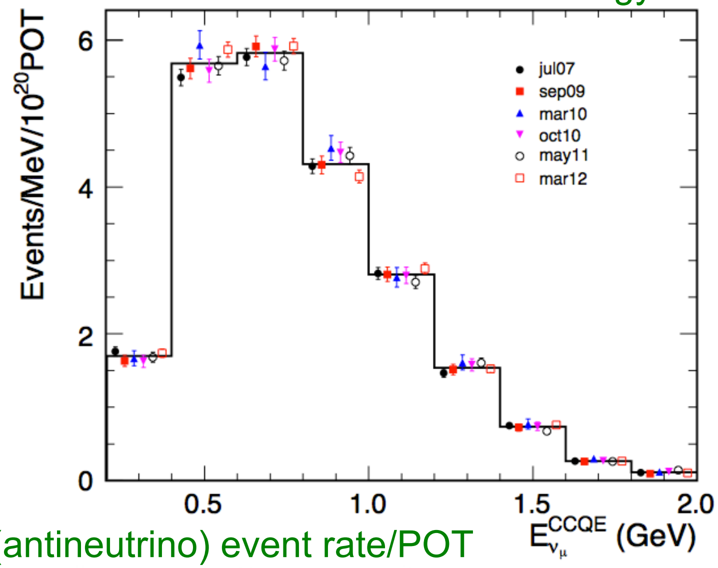
2. MiniBooNE detector



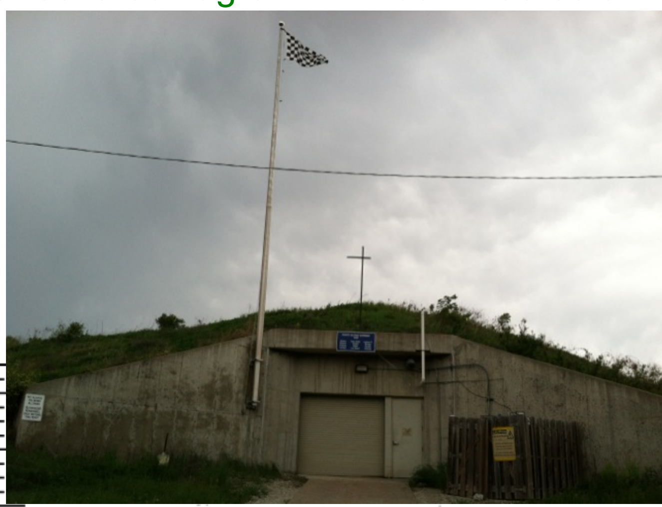
MiniBooNE run is over!

- 2002 to 2012 (proposals prepared for further running)
- extremely stable running over 10 years
  - energy scale is stable within 1%
  - Neutrino rate is stable with 2%

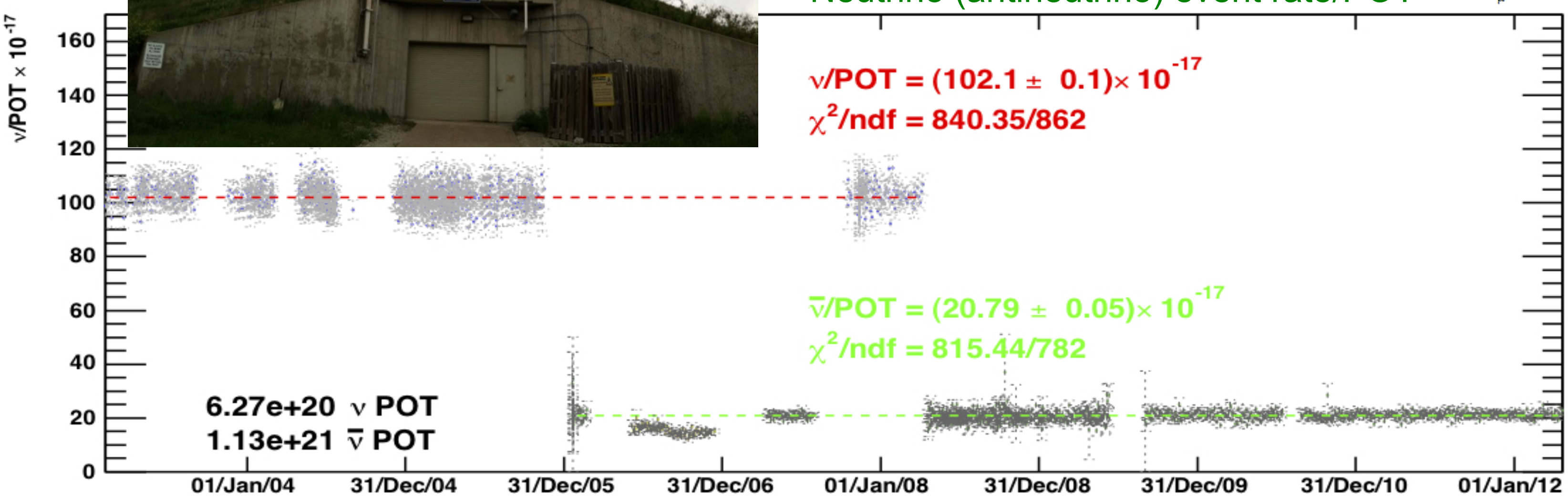
Reconstructed neutrino energy



Checkered flag on MiniBooNE detector hall



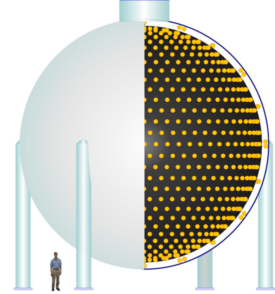
Neutrino (antineutrino) event rate/POT

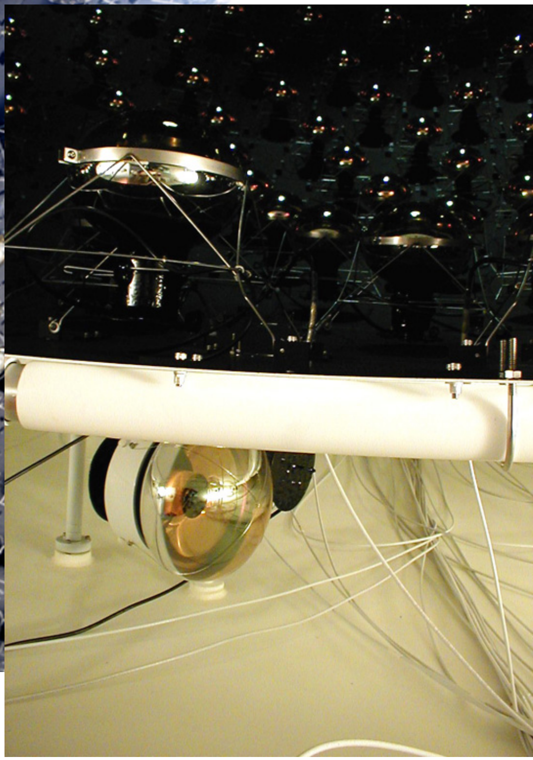


MiniBooNE collaboration,
PRD81(2010)092005

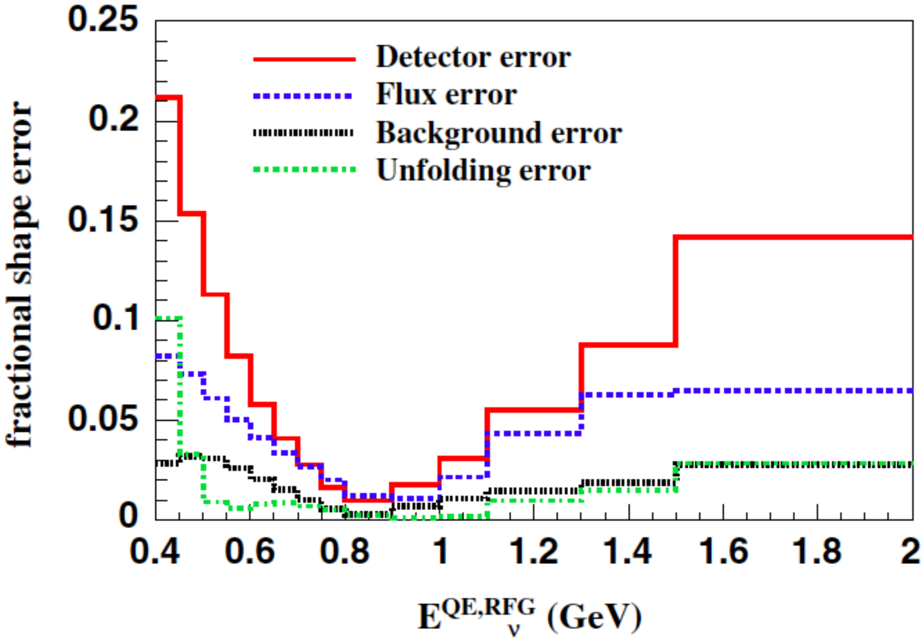
2. MiniBooNE detector

MiniBooNE, as a Cherenkov detector
- 12 m diameter spherical tank
- 800t of pure mineral oil (from Exxon)
- 1280 inner 8-inch PMTs
- 240 veto 8-inch PMTs
- Detector errors are small comparing with flux error, total normalization error is 4-5%
- But it has large shape error



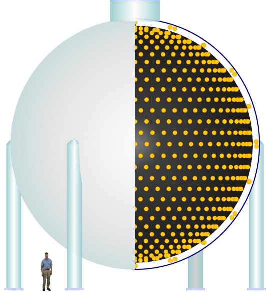


CCQE flux-unfolded total cross section fractional shape error



Perevalov, PhD thesis
PRD82(2010)092005

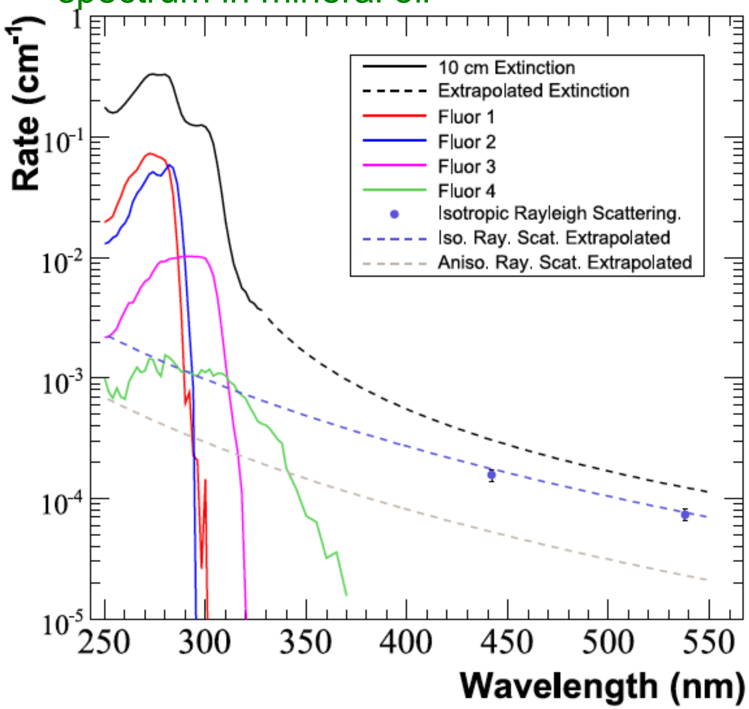
2. MiniBooNE detector



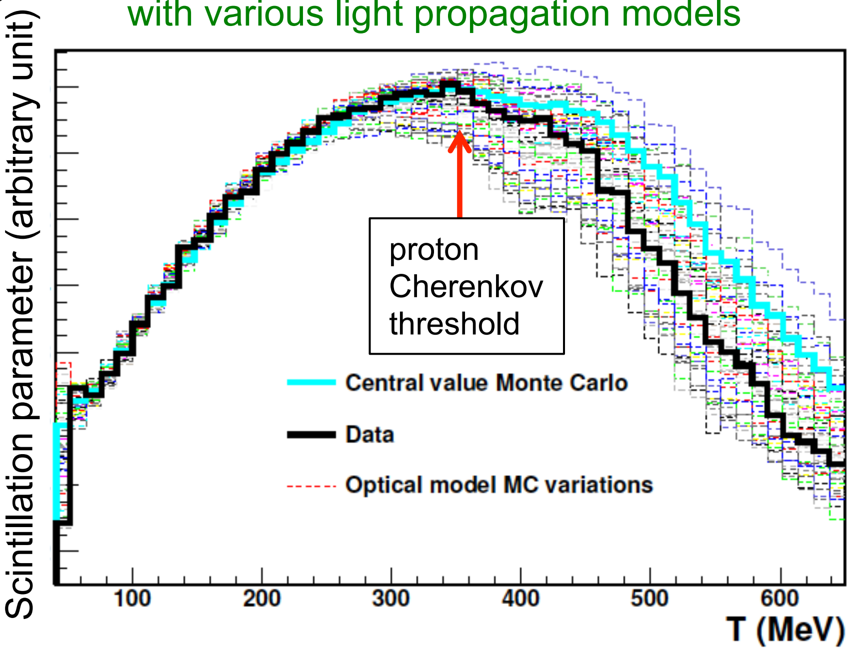
MiniBooNE, as a scintillation detector

- Scintillation from the mineral oil represent total deposit energy (nuclear effect-free!)
- Light propagation model creates large source of uncertainty
- NCEL measurement is limited by this detector error (16%)

Light extinction rate for each absorption spectrum in mineral oil



NC elastic scintillation light fraction with various light propagation models



Tayloe, Fermilab 2012
PAC presentation

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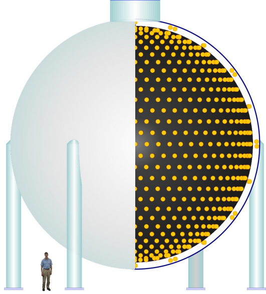

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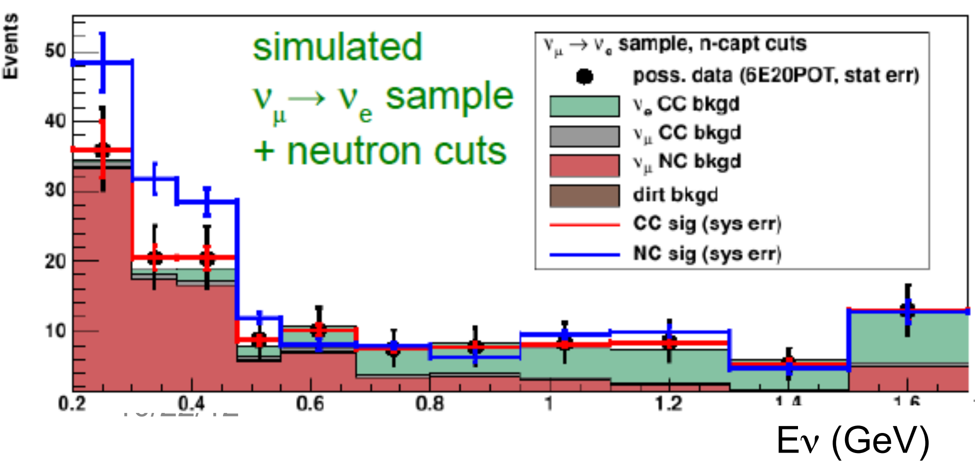
Adding scintillator in MiniBooNE detector?

- Proposal is considered
- Possible to detect 2.2MeV γ from neutron capture
- 300kg of PPO ($75k) can do that

Physics

- Improve NCEL measurement
- Can distinguish ν_eCCQE from NC processes (NCγ, NCπ^o) by neutron tagging
- ν_μ+C$\rightarrow\mu$+N$_{g.s.}$ measurement by N$_{g.s.}$ β-decay
- Eν reconstruction by total scintillation light



Eν calibration by scintillation light, see Tzanov's talk on today

Nelson, PhD thesis
PRD83(2011)052009

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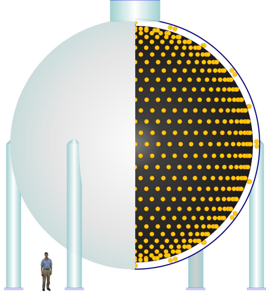
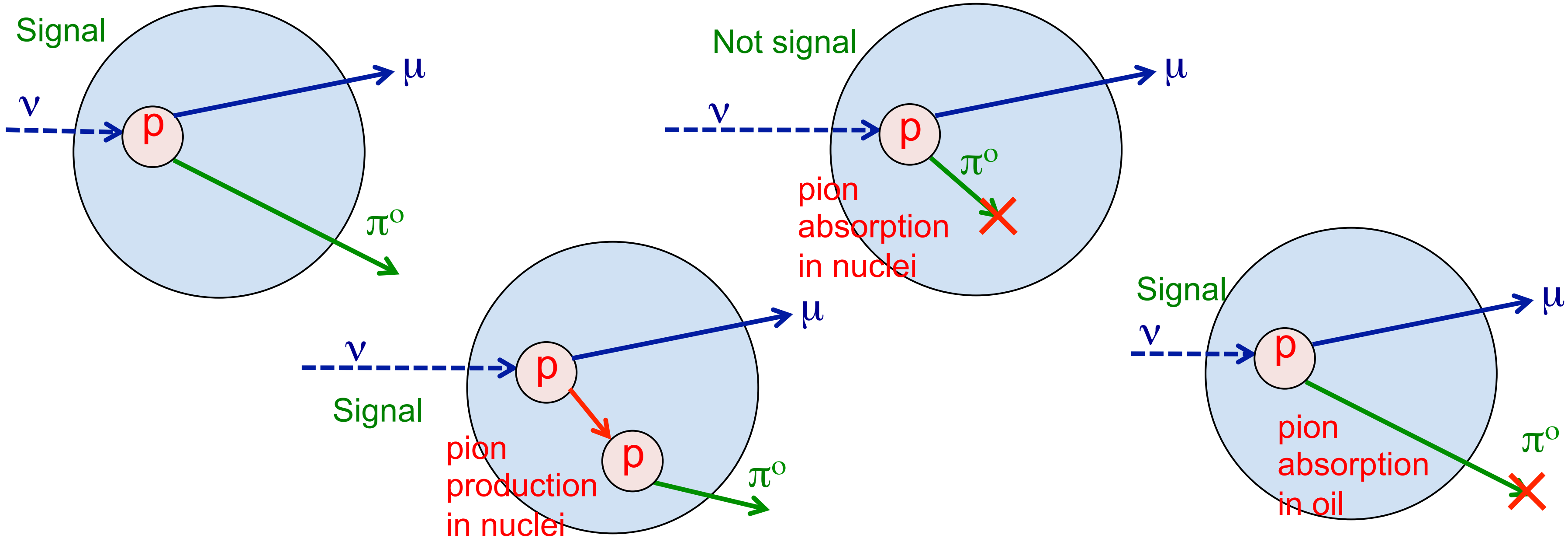


Nuclear effects in the MiniBooNE detector
- Cross section model error only affect background subtraction
- All cross sections are defined by final state particles, hence MiniBooNE cross section measurement has no intra-nuclear effect error
- However propagation of particles in the detector is also affected by nuclear effect (e.g., pion absorption by oil, etc) and this have to be modelled, and corrected. CC1π^o production measurement is limited by this (13%)



Nelson, PhD thesis
PRD83(2011)052009

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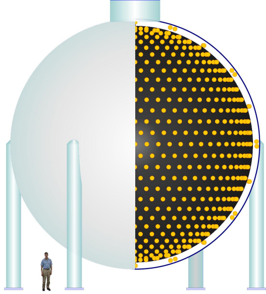

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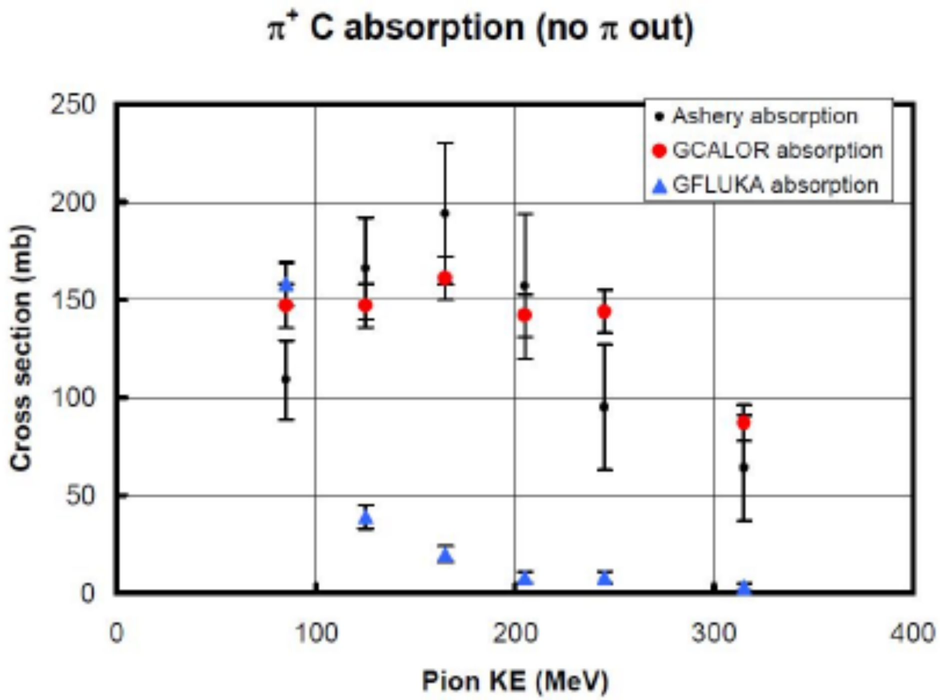
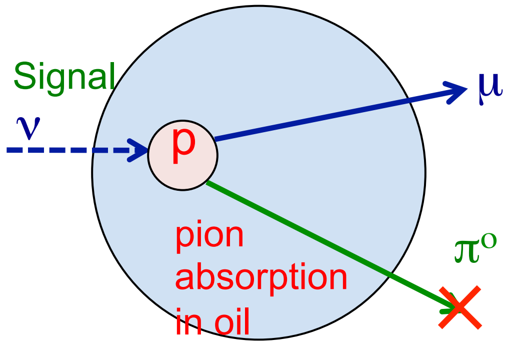


GCALOR-data comparison

- pion charge exchange in the detector → 50%
- pion absorption in the detector → 35%



Anderson, PhD thesis
PRD81(2010)033004

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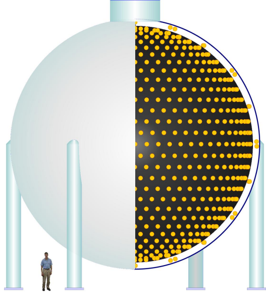
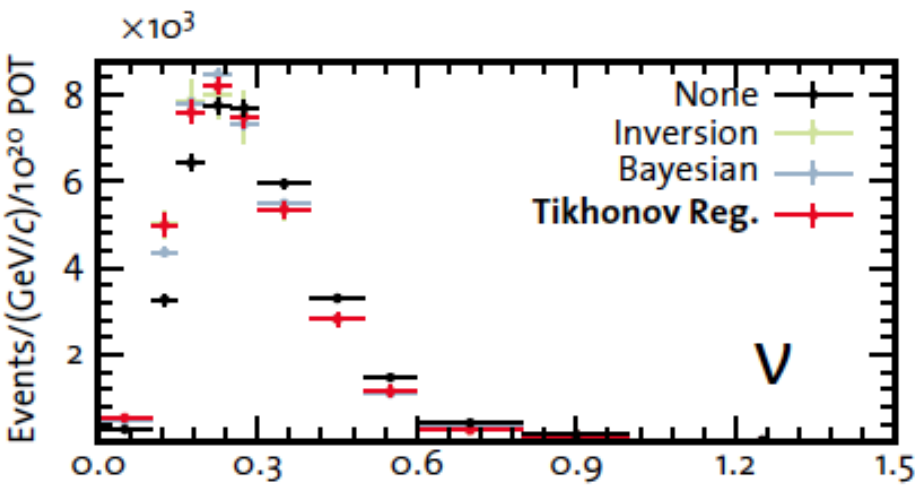
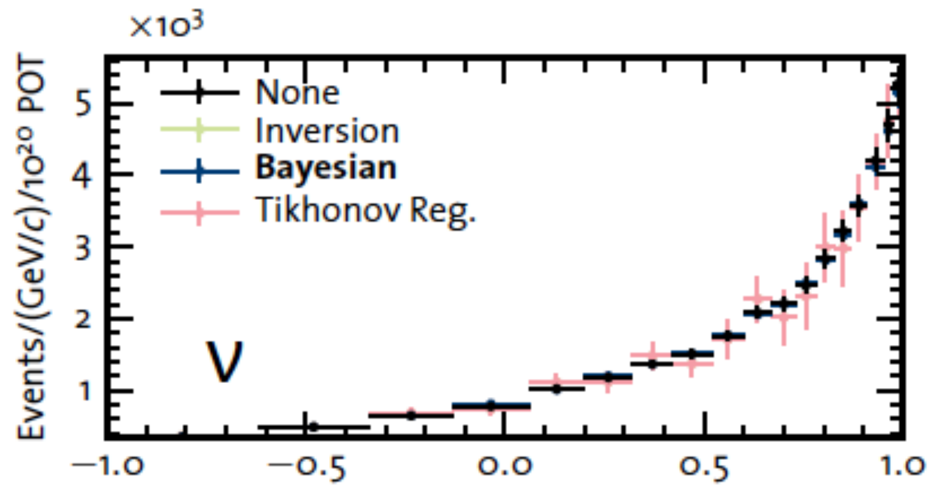


MiniBooNE data unfolding error

- Extracted cross section depends how to unfold, hence there is unfolding error
- Most of MiniBooNE xs data rely on Iterative Bayesian unfolding method, which depends on cross section model, but model dependency is corrected by iterative process
- There is no perfect unfolding method (small bias doesn't mean better)



NC1π^o production momentum distribution (GeV/c)



NC1π^o production angular distribution

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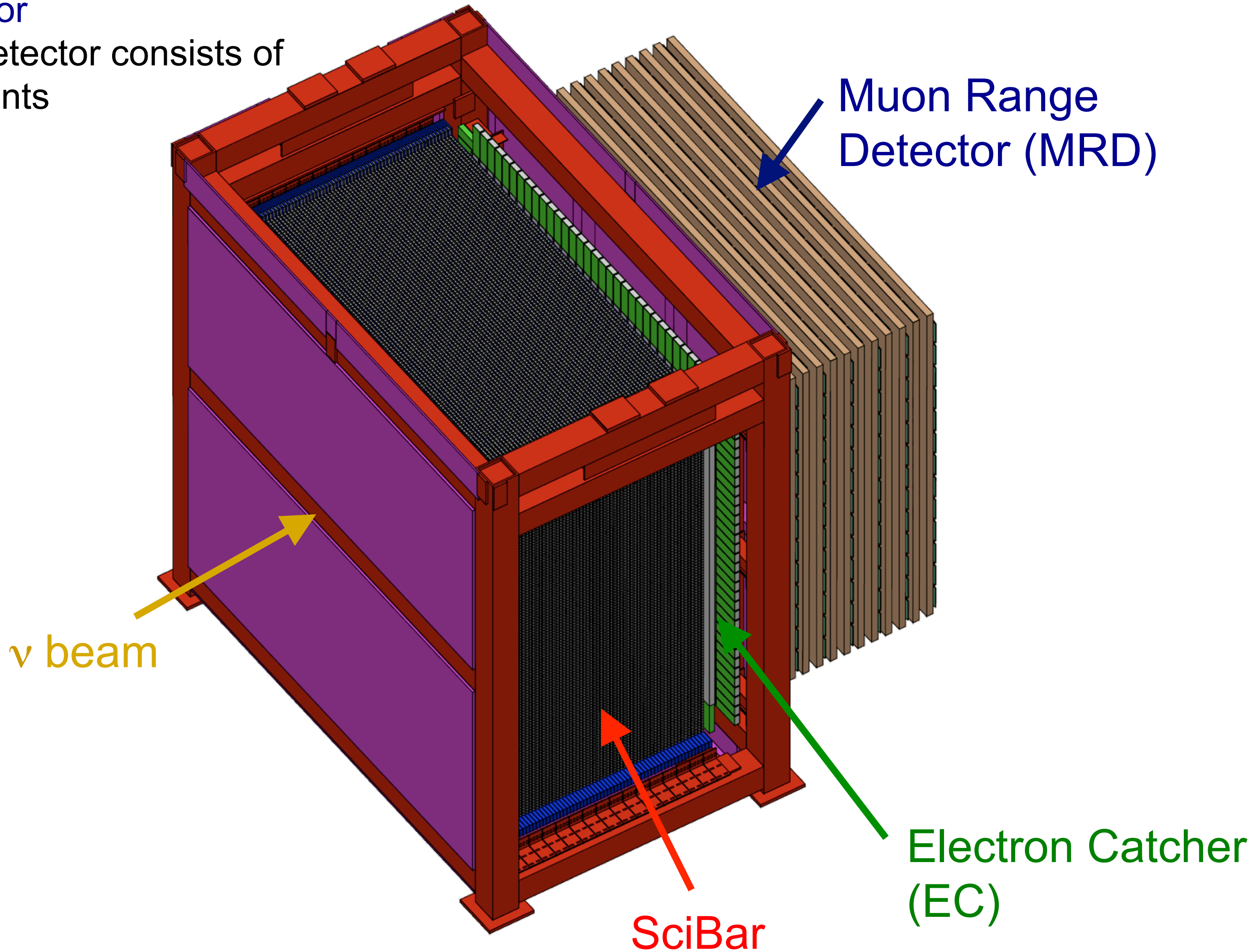
SciBooNE detector

The SciBooNE detector consists of 3 major components



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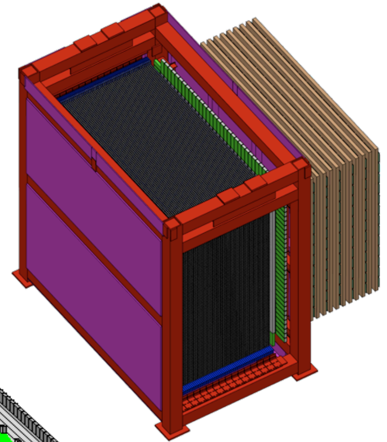
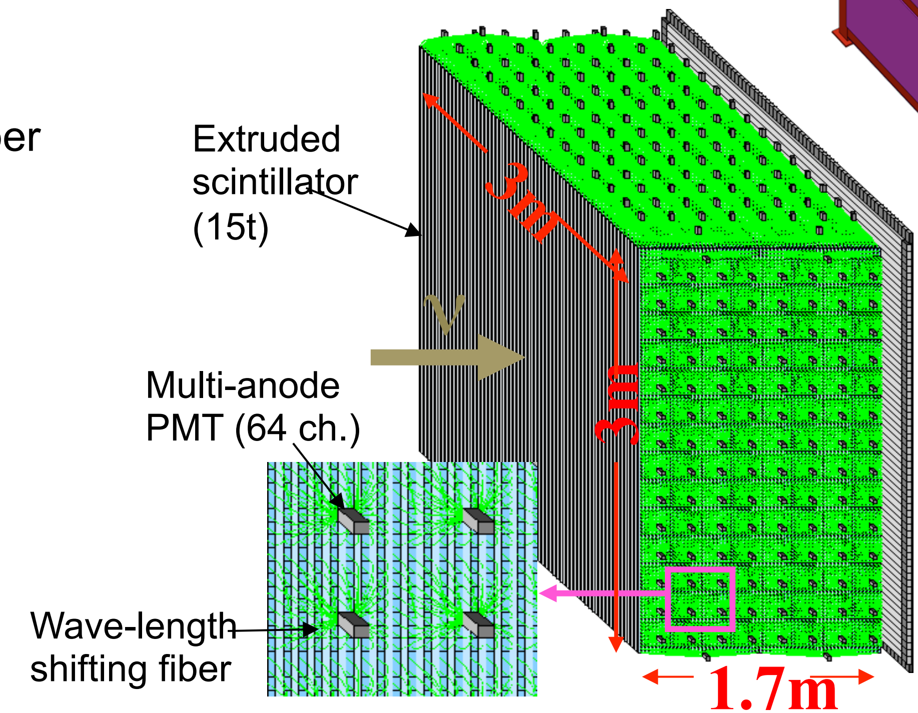


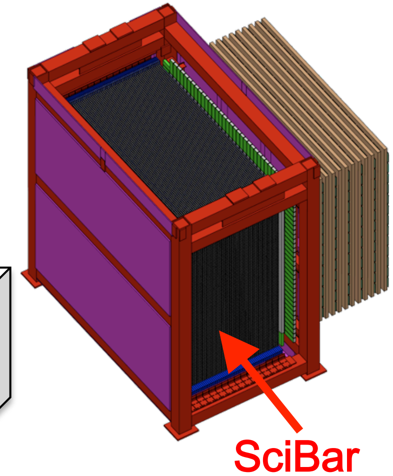
SciBar detector
- 14,366 channel X-Y tracker of extruded scintillators with WLS fiber readout by multi-anode PMT.



Electron catcher (EC)
- 11 radiation length E&M calorimeter with scintillation fibers and lead foil.

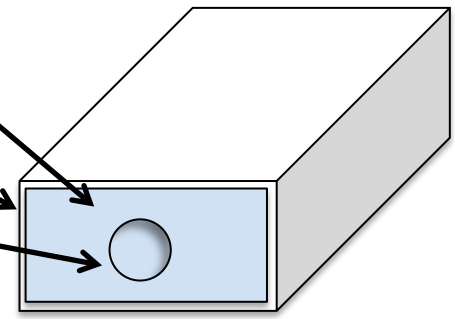
Muon Range Detector (MRD)
- Iron plates with X-Y scintillator panels
- measure the muon momentum up to 0.9GeV, with 10% resolution.

3. SciBooNE detector



Extruded scintillation bar

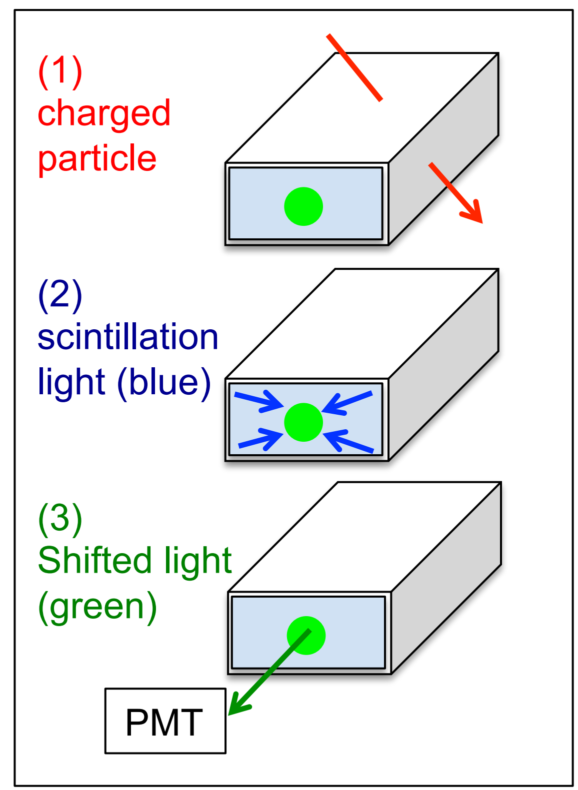
- Polystyrene (PS), 1% PPO and 0.03% POPOP
- TiO_2 is merged in outer layer as a reflector
- hole for WLS fiber
- ~20 p.e. for MIP particle
- K2K, MINOS, SciBooNE, MINERvA, T2K...



Wave length shifting (WLS) fiber

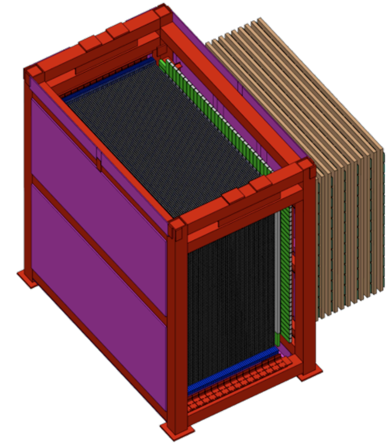
- Absorb blue light, emit green light

Extruded scintillator production machine (Fermilab)




Y01Z4
C117

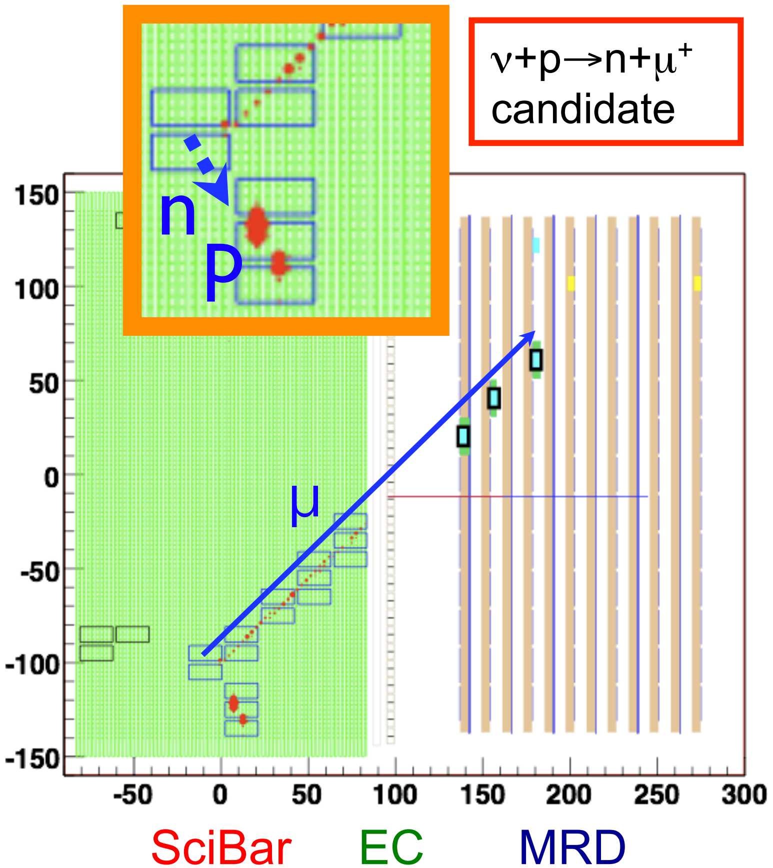
3. SciBooNE detector

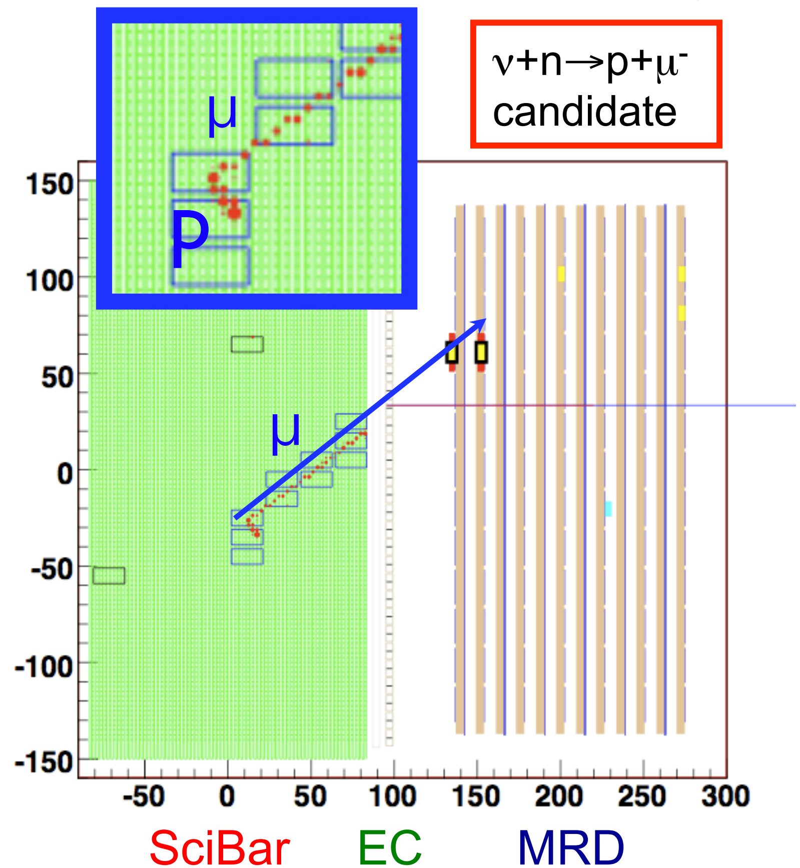


SciBar tracking ability

- Particle tracks are clearly seen

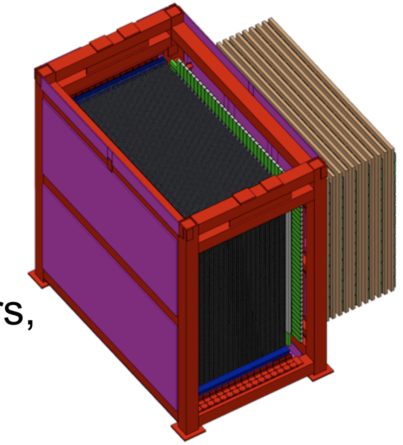
SciBooNE CCQE candidate





Hiraide, PhD thesis
PRD78(2008)112004

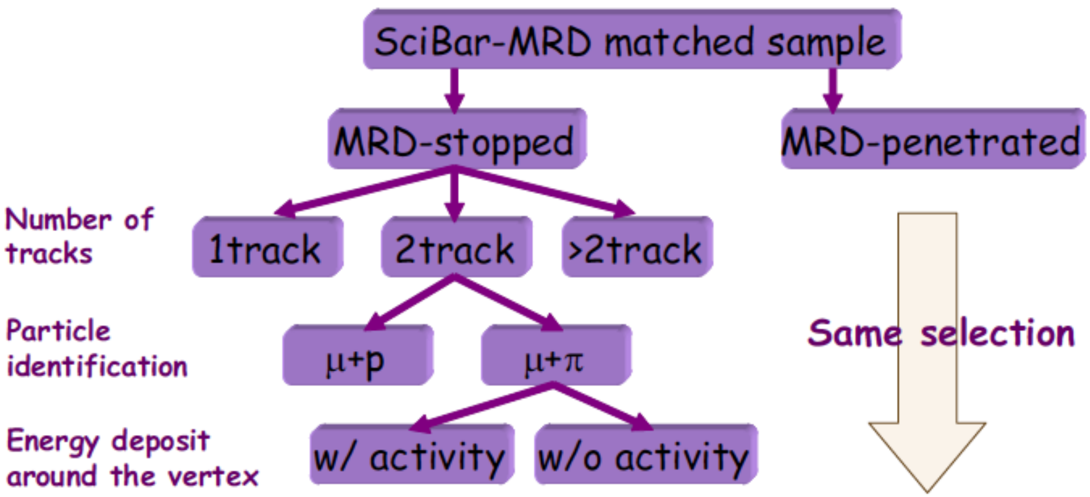
3. SciBooNE detector



It is extremely difficult to be right for all samples, 1 track, 2 track, μ+p, etc...
- Within detector systematics, cross section model errors, nuclear effect errors, MC is tuned to match with data

e.g.) CC1π^+ production measurement analysis
- 8 parameter controls total normalization, migrations, scale of some channels
- Best fit MC is used for background subtraction

SciBooNE CC1π^+ analysis flowchart

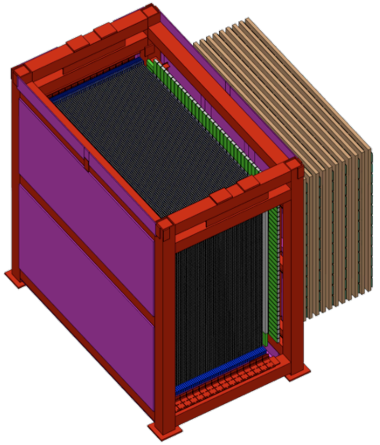


Best fit values

Parameter	Value	Error
R_{norm}	1.103	0.029
$R_{\mathrm{2trk/1trk}}$	0.865	0.035
$R_{p/\pi}$	0.899	0.038
R_{act}	0.983	0.055
R_{pscale}	1.033	0.002
R_{res}	1.211	0.133
R_{other}	1.270	0.148
κ	1.019	0.004

Nakajima, PhD thesis,
PRD83(2011)012005

3. SciBooNE detector



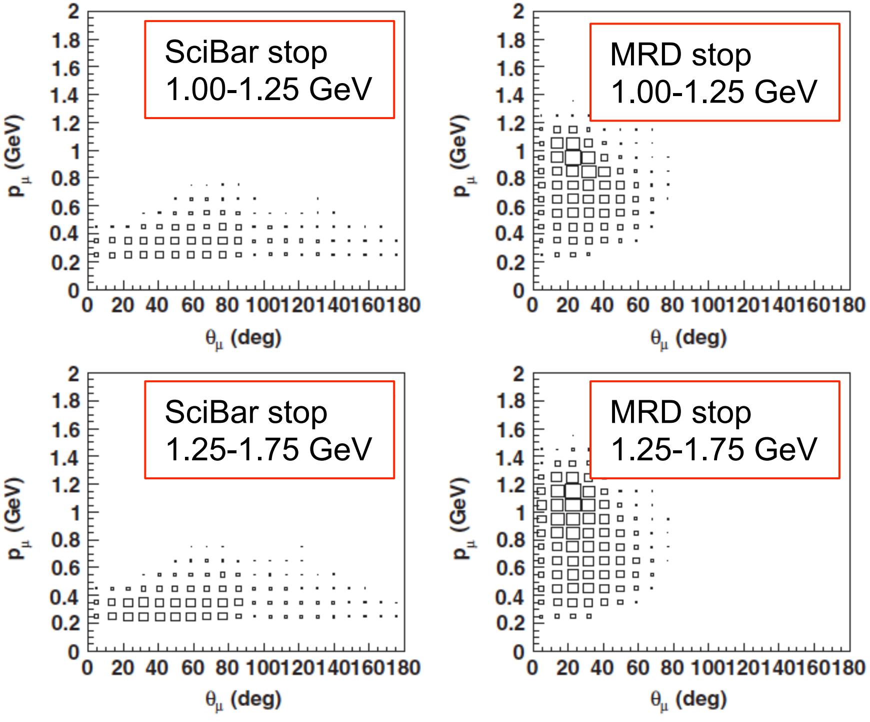
SciBooNE cross section model error

- Unlike MiniBooNE, cross section model errors are included

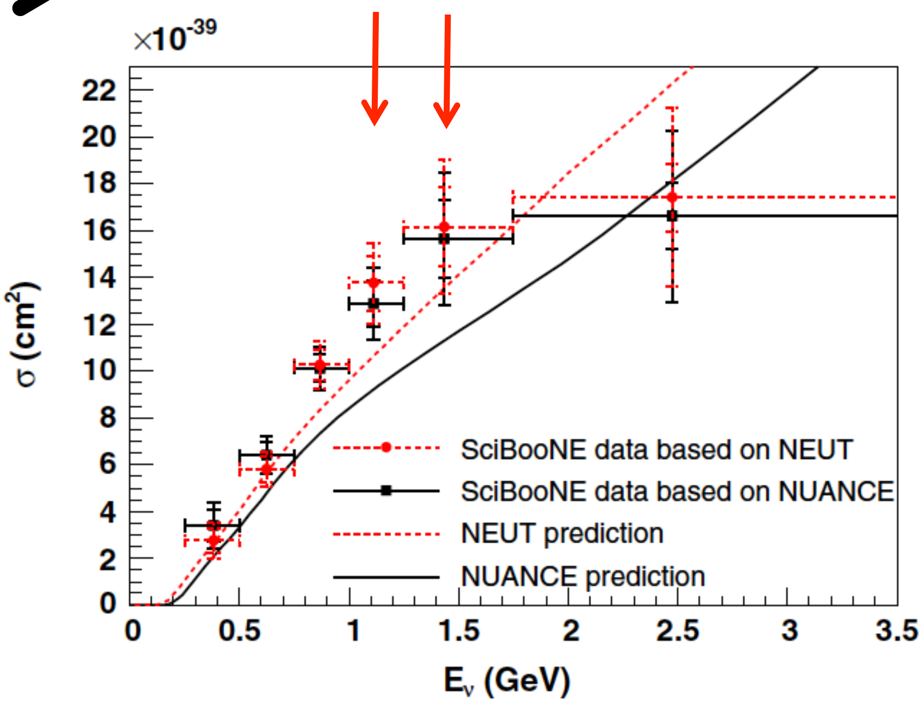
e.g.) CC inclusive cross section

- MC template in P_μ-θ_μ space is used to extract total cross section

P_μ-θ_μ space MC template in Eν bin

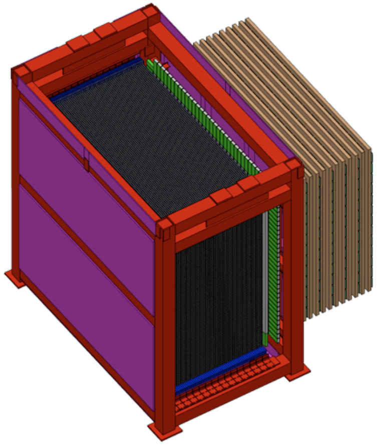


Extracted total cross section



Kurimoto, PhD thesis
PRD81(2010)111102(R)

3. SciBooNE detector

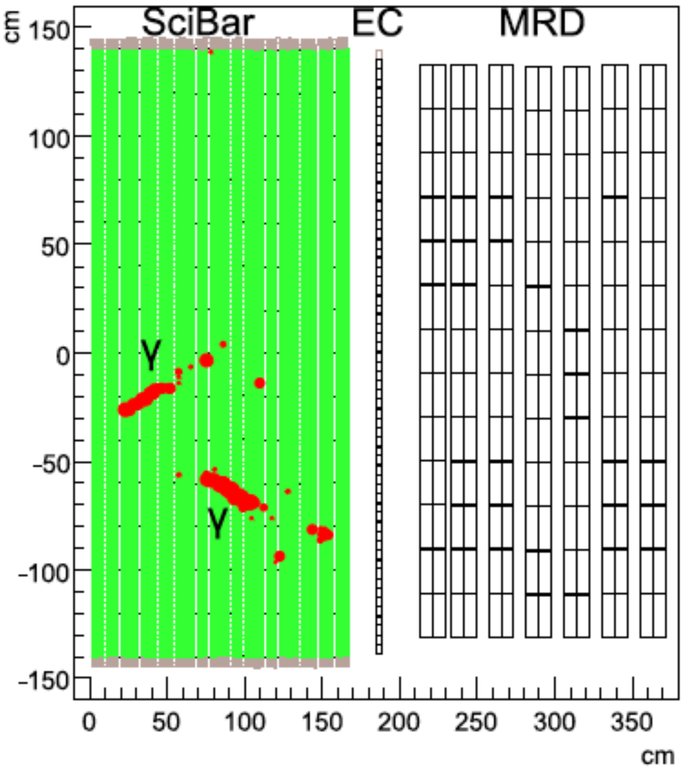


Vertex activity

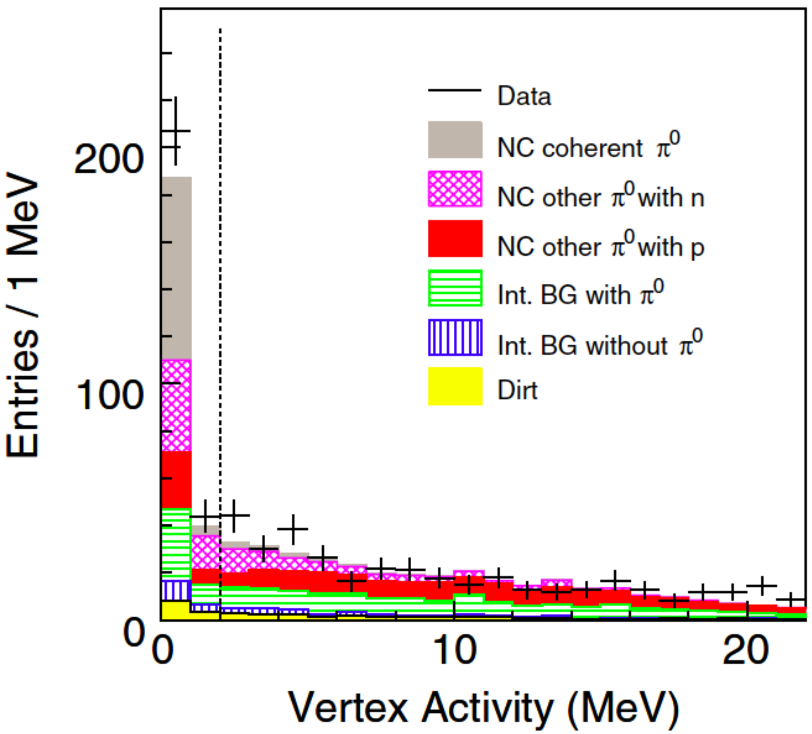
- Energy deposit around the vertex can be measured.
- Especially powerful to study nuclear break-up (i.e. coherent reaction)

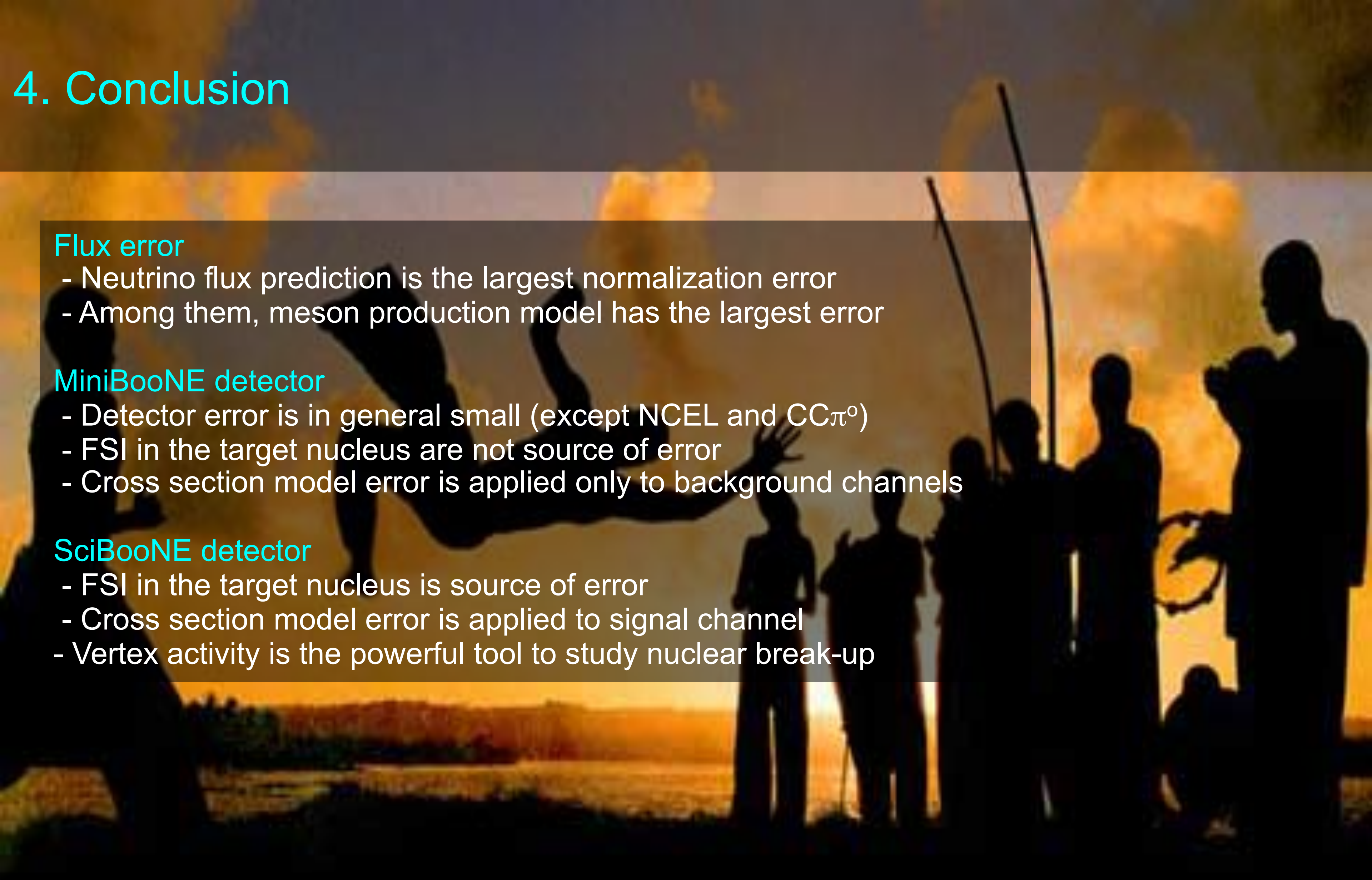
e.g.) NCπ^o coherent fraction measurement

SciBooNE NC1π^o event display



NCπ^o vertex activity





4. Conclusion

Flux error
- Neutrino flux prediction is the largest normalization error
- Among them, meson production model has the largest error

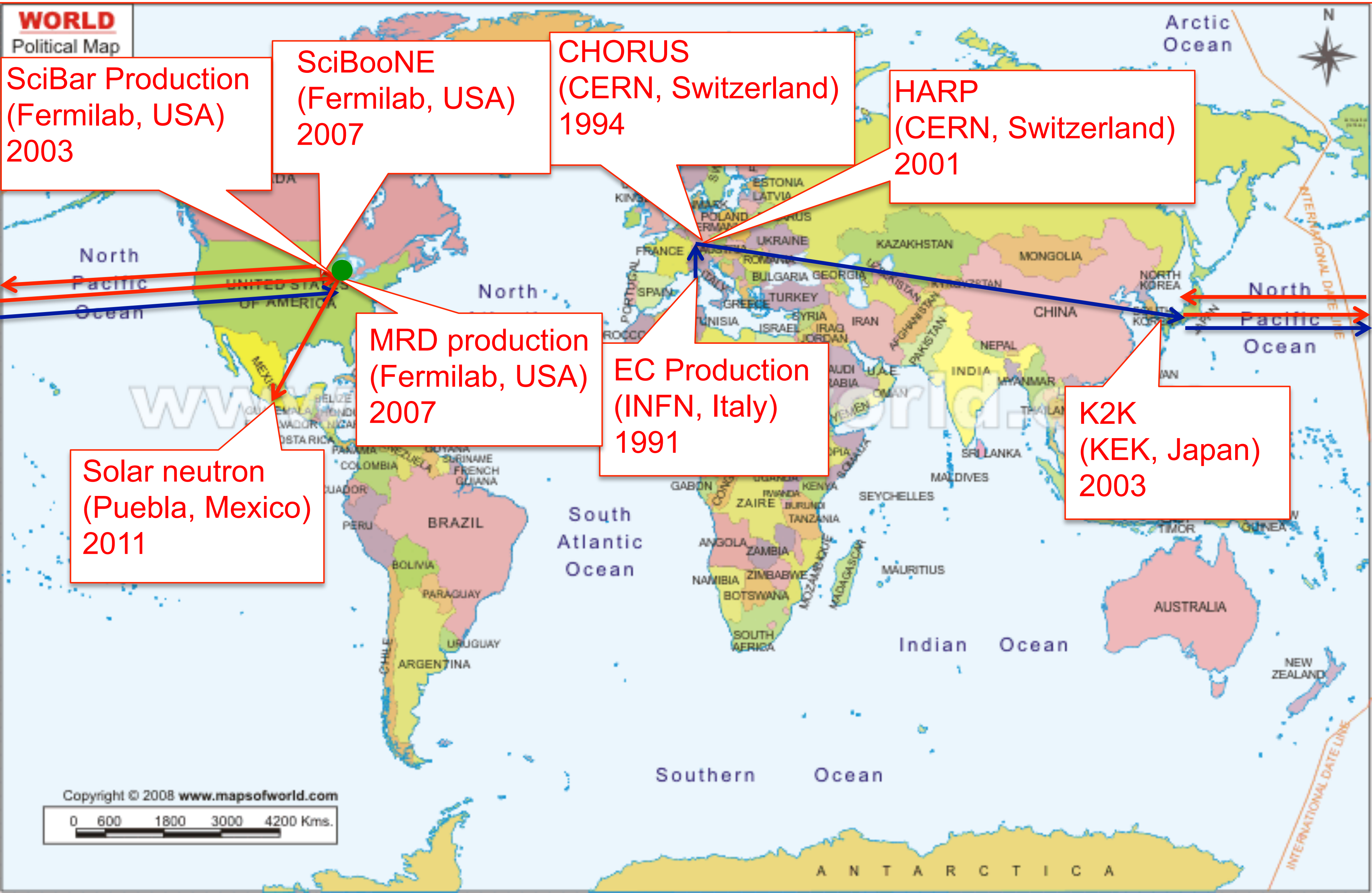
MiniBooNE detector
- Detector error is in general small (except NCEL and $CC\pi^o$)
- FSI in the target nucleus are not source of error
- Cross section model error is applied only to background channels

SciBooNE detector
- FSI in the target nucleus is source of error
- Cross section model error is applied to signal channel
- Vertex activity is the powerful tool to study nuclear break-up

Muito obrigado!

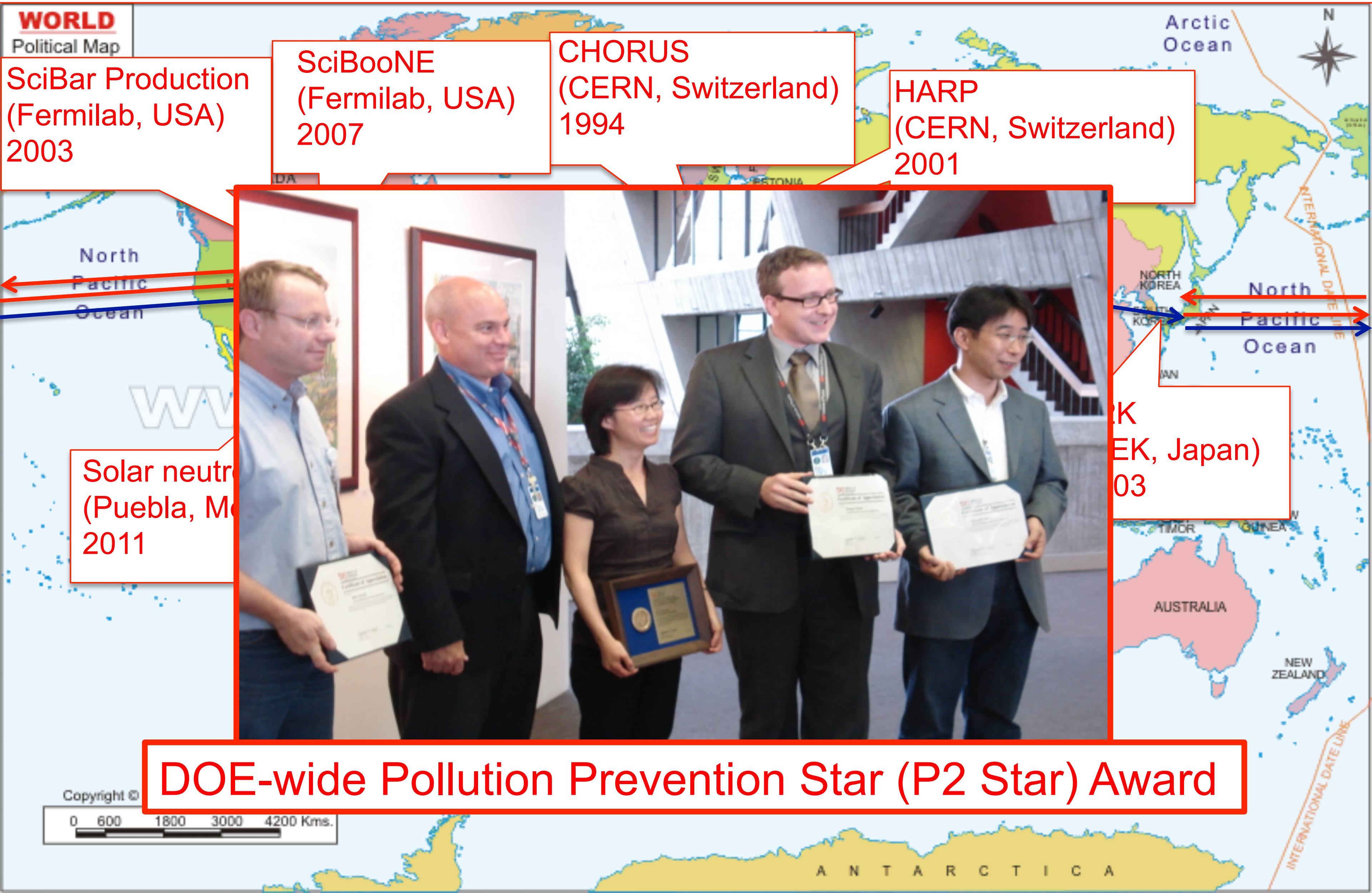
Backup

3. SciBooNE detector all around the world



3. SciBooNE detector all around the world

SciBar
EC
MRD



SciBar Production
(Fermilab, USA)
2003

SciBooNE
(Fermilab, USA)
2007

CHORUS
(CERN, Switzerland)
1994

HARP
(CERN, Switzerland)
2001

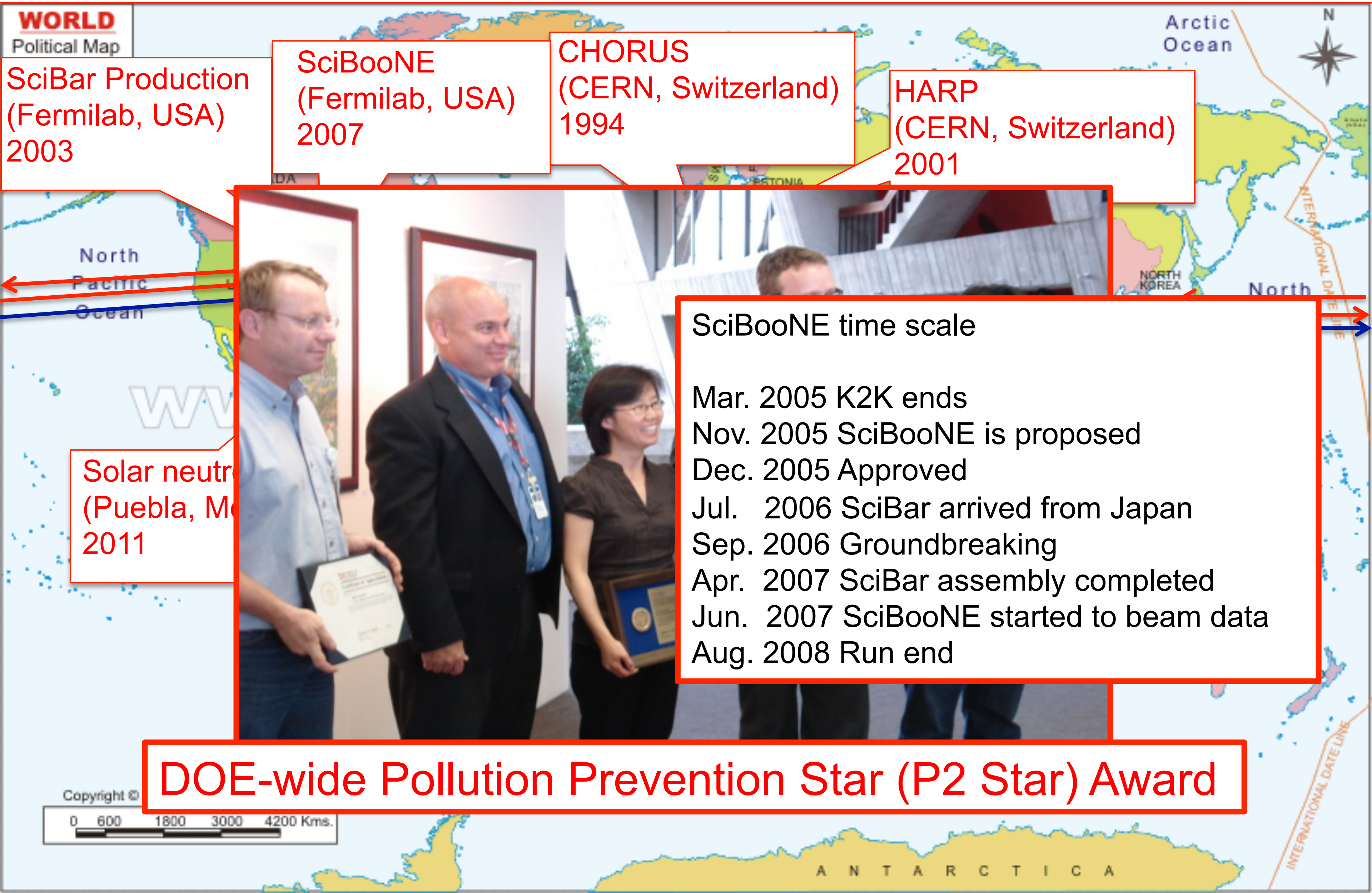
Solar neutr
(Puebla, M
2011

K
EK, Japan)
03

DOE-wide Pollution Prevention Star (P2 Star) Award

3. SciBooNE detector all around the world

SciBar
EC
MRD



SciBar Production
(Fermilab, USA)
2003

SciBooNE
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2007

CHORUS
(CERN, Switzerland)
1994

HARP
(CERN, Switzerland)
2001

Solar neutr
(Puebla, M
2011

SciBooNE time scale

Mar. 2005 K2K ends
Nov. 2005 SciBooNE is proposed
Dec. 2005 Approved
Jul. 2006 SciBar arrived from Japan
Sep. 2006 Groundbreaking
Apr. 2007 SciBar assembly completed
Jun. 2007 SciBooNE started to beam data
Aug. 2008 Run end

DOE-wide Pollution Prevention Star (P2 Star) Award